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# Simulation of permafrost changes due to technogenic influences of different engineering constructions used in northern oil and gas fields

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## Abstract.

Significant amount of oil and gas is produced in Russian Federation on the territories with permafrost soils. Ice-saturated rocks thawing due to global warming or effects of various human activity will be accompanied by termocarst and others dangerous geological processes in permafrost. Design and construction of well pads in permafrost zones have some special features. The main objective is to minimize the influence of different heat sources (engineering objects) inserted into permafrost and accounting long-term forecast of development of permafrost degradation due to different factors in particular generated by human activity. In this work on the basis a mathematical model and numerical algorithms approved on 11 northern oil and gas fields some effects obtained by carrying out numerical simulations for various engineering systems are discussed.

## 1. Introduction

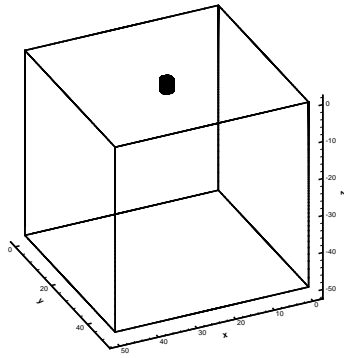
Regions of permafrost take about 75% of territory of Russia. Preservation of ecological balance is an important problem depending both of climate changes and human activity [1]. These regions are intensively involved in oil and gas production and these efforts have a significant effect on permafrost due to heat from tubes with oil in the wells leads to thawing and possible hazards related with destruction of soils [2, 3]. Not only well and pipelines but also there are a number of buildings, constructions and tanks, which serving the oil production may lead to permafrost degradation. These processes generate significant difficulties in construction and operation of various engineering structures. Most of buildings in permafrost regions are designed such a way to decrease the thermal influence on the soil.

Numerical simulation is an effective method to estimate the results of thermal influence of objects inserted in permafrost and allow to choose more safe insulations and construction. In accordance with [4, 5] simulation of heat distribution in permafrost is a problem of solution of three-dimensional thermal conductivity equations with nonhomogeneous coefficients, including localized specific heats of phase transition — an approach that allows to solve the problem of the Stefan type without explicit separation phase transition boundary. In papers [6–8] are presented a mathematical model of heat distribution with nonlinear boundary condition, numerical algorithm and codes including with parallel computing approach [9]. In [10] this model is also consider filtration of fluid in soil as heat conduction mode. Let consider application of

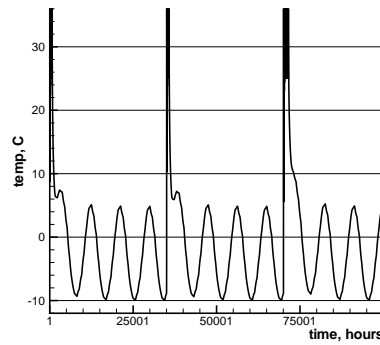


this to solution of a problem of constructing and exploitation of some reservoirs in permafrost area.

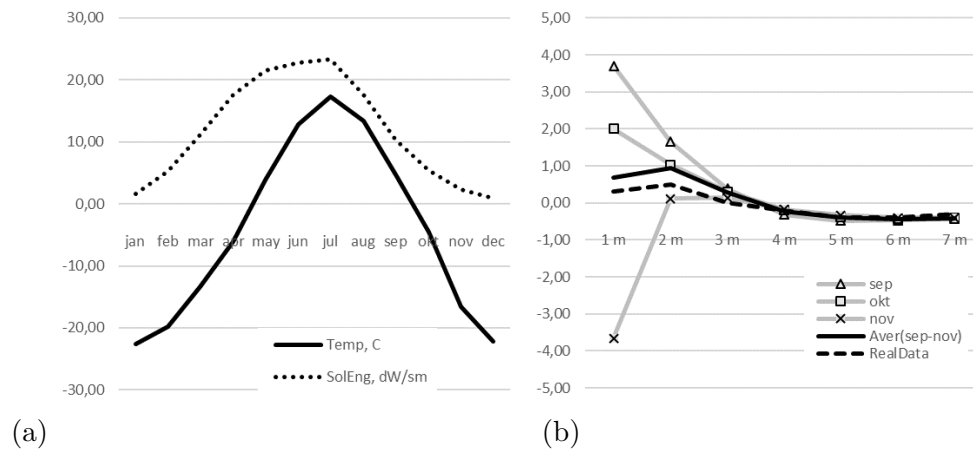
## 2. Object of simulation



**Figure 1.** The area with reservoir.



**Figure 2.** Changes of temperature in reservoir, °C.



**Figure 3.** (a) — montly average air temperature (solid) and solar radiation (dotted). (b) — temperature in soil on autumn in measured (dashed) data and computed data (solid lines).

In a three-dimensional area (fig. 1) a tank which has cylindrical form is considered as a heat source. To simulate long-time influence of this object inserted into permafrost soil we will compute an annual thermal field in the soil taking into account a number of essential climatic factors related with the place under consideration [3, 8]. In Fig 3(a) montly average air temperature and intensity of solar radiation are presented. Temperature of permafrost except for the layer of seasonal thawing (freezing) of soil (ALT), is assumed equal to  $-0,3^{\circ}\text{C}$ .

The equation of heat conductivity has the form

$$\rho(c_v(T) + k\delta(T - T^*)) \frac{\partial T}{\partial t} = \nabla (\lambda(T) \nabla T), \quad (1)$$

with initial condition

$$T(0, x, y, z) = T_0(x, y, z), \quad (2)$$

where  $\rho$  is density [ $kg/m^3$ ],  $T^*$  is temperature of phase transition [ $K$ ],

$$c_\nu(T) = \begin{cases} c_1(x, y, z), & T < T^*, \\ c_2(x, y, z), & T > T^*, \end{cases} \text{ is specific heat [J/kg K],}$$

$$\lambda(T) = \begin{cases} \lambda_1(x, y, z), & T < T^*, \\ \lambda_2(x, y, z), & T > T^*, \end{cases} \text{ is thermal conductivity coefficient [W/m K],}$$

$k = k(x, y, z)$  is specific heat of phase transition,  $\delta$  is Dirac delta function.

The boundary condition at the upper boundary are

$$\gamma q + b(T_{air} - T(x, y, 0, t)) = \varepsilon \sigma (T^4(x, y, 0, t) - T_{air}^4) + \lambda \frac{\partial T(x, y, 0, t)}{\partial z}, \quad (3)$$

and includes climatic the parameters such as solar radiation  $q$ , air temperature  $T_{air}$ , a part of energy  $\gamma$  for the soil heating and coefficient of emissivity of the surface  $\varepsilon \sigma$ . At the bottom and lateral boundaries the zero flux conditions are assumed.

Numerical methods of solving problems are the most effective and universal method of research for models considered in this paper. A large number of works is devoted to development of difference methods for solving boundary value problems for the heat equation To solve (1)–(3) a finite-difference method is used.

With using these ideas [4, 5], to solve problem (1)–(3) in three-dimensional box a finite difference method is used with splitting by the spatial variables and taking into account the inner boundaries of the reservoir. Solvability of the same difference problems approximating is proved in [6] in the case of thermal traces of of underground pipelines without phase transition in soil [11].

In the condition (3) the values of intensity of solar radiation and seasonal changes in air temperature are given by weather stations. Fig. 3(a) shows the data for the considered field. The soil parameters in (1) are determined as a result of geophysical research of oil and gas field.

Applying the developed iterative algorithm [7, 12] to define some of the parameters in nonlinear boundary condition (3) it is possible to identify them so that the temperature distribution in the soil found as a solution of equation (1)–(3) to be periodically repeated, that allows to implicitly take into account different climate and natural features of the considered geographical location.

To approve the model and algorithm of computations it is necessary to compare the numerical results and measured data. In Fig. 3(b) a real temperature distribution in soil on autumn is presented (dashed black line) in compare with computed data (gray and black solid lines), which are in good agreement and the temperature distribution periodically repeated. Moreover, the thickness of ALT in measures reaches 5,6–6,0m in different incisions, in computations it takes approximately 5,7–5,8m.

### 3. Numerical results

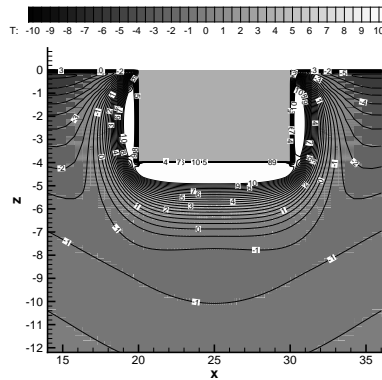
Consider a computational area having the form of a box (fig 1). As a basic soil we will use a loam with the following parameters. Thermal conductivity: frozen — 2,79 W/(m K), melted — 2,67 W/(m K), volumetric heat: frozen — 2176 kJ/(m<sup>3</sup> K), melted — 2594 kJ/(m<sup>3</sup> K), volumetric heat of phase transition — 1.376·10<sup>5</sup> kJ/(m<sup>3</sup> K). The background temperature of permafrost is -1.5C, except for the layer of seasonal thawing (freezing) of soil (ALT). Soil is a sandy loam with parameters:

We will consider 3 types of tanks:

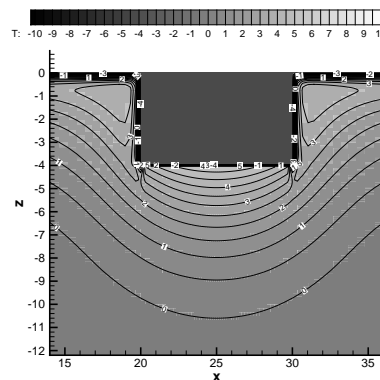
**I-st tank** is an open-top reservoir with 10m diameter, deep is 4m. The shell consists of two layers: 0,3m of concrete (thermal conductivity — 1,69 W/(m K) density — 2500,0 kg, specific

heat —  $840,0 \text{ J/(kg K)}$  ) and  $0,072\text{m}$  of penoplex (thermal conductivity —  $0,47 \text{ W/(m K)}$  density —  $1600,0 \text{ kg}$ , specific heat —  $840,0 \text{ J/(kg K)}$  ).

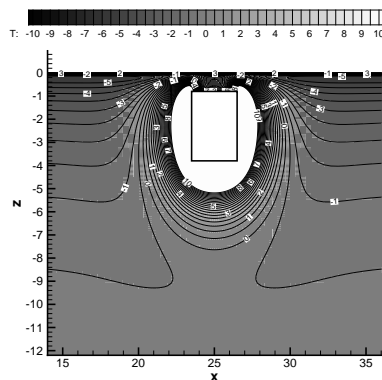
**II-nd tank** is an underground reservoir with  $3\text{m}$  diameter, deep is  $4\text{m}$  and height is  $2,3\text{m}$ . The shell consists of two layers:  $0,1\text{m}$  of concrete and  $0,072\text{m}$  of penoplex.



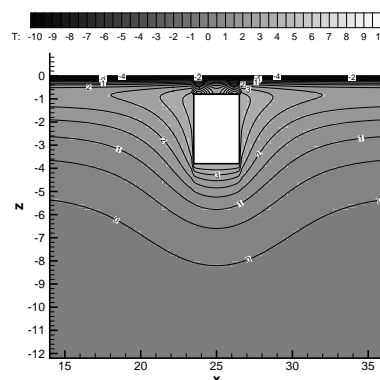
**Figure 4.** Temperature around I-st tank. May.



**Figure 5.** Temperature around I-st tank. October.



**Figure 6.** Temperature around II-nd tank. May.



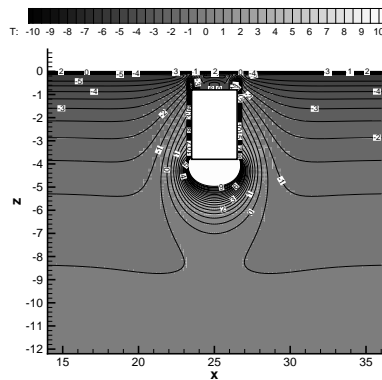
**Figure 7.** Temperature around II-nd tank. October.

**III-rd tank** is an underground reservoir with  $3\text{m}$  diameter, deep is  $4\text{m}$  and height is  $2,3\text{m}$ . The shell consists of two layers:  $0,1\text{m}$  of concrete and  $0,288\text{m}$  of penoplex.

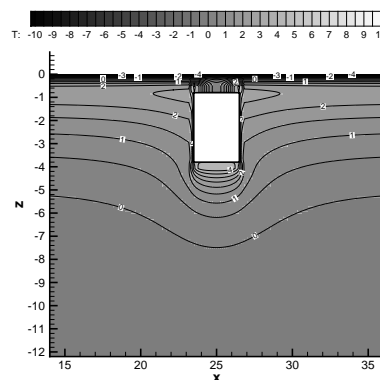
We will assume that temperature in the tank varying as follows: one months (may) in 4 years it is in using (is heated up to  $50^\circ\text{C}$  ), and all the rest of the time it takes air (I-st tank) or soil (II-nd and II-rd tanks) temperature. In Fig. 2 the temperature in the tanks are shown during the time.

In Figs. 4–9 the thermal fields in a vertical section of computational domain with tanks are presented for may when the reservoirs are used (figs. 4,6,8) and for october (figs. 5,7,9). Deep of thawing (zero-isotherm) depends not only by insulating of the tanks (II-nd and III-rd tanks), but also and by the size of reservoir (I-st tank).

It is necessary to note that when the insulating layer is larger, it is not always good for conservation of permafrost. In Fig. 10 the profiles of temperature under II-nd (fig. 10a) and III-rd (fig. 10b) tanks are presented. Indeed, for much better insulated III-rd tank the heat

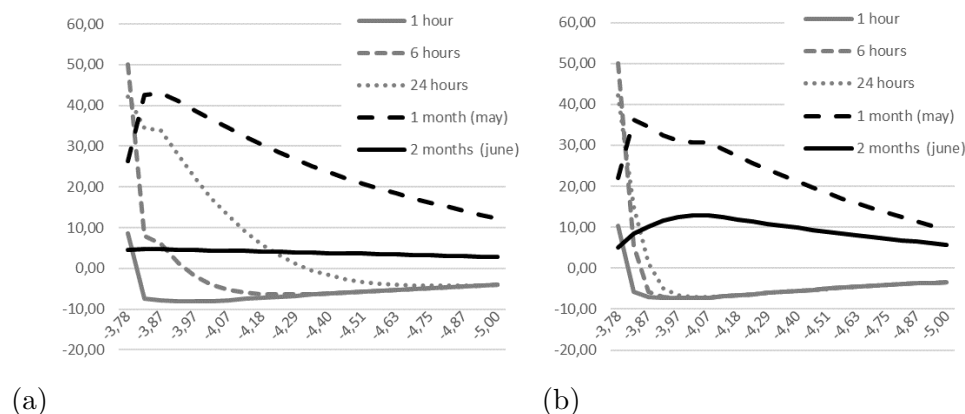


**Figure 8.** Temperature around III-rd tank. May.



**Figure 9.** Temperature around III-rd. October.

propagates not so intensively as for II-nd tank, but in long-time perspective, the thick layer of insulation prevents natural heat diffusion and cooling of the soil. So that an overheating of the bottom takes place.



**Figure 10.** Temperature under tank.

#### 4. Conclusion

The suggested mathematical model of heat distribution and numerical algorithm of solution and program code allows to carry out a series of numerical experiments to make predictions about long-term dynamics of permafrost thawing related with different regimes of exploitation of engineering constructions. These methods are approved by the comparison with experimental data obtained during a number of exploitations of oil and gas field. The results of numerical simulations allow to evaluate the effectiveness of thermal stabilization of soil.

##### 4.1. Acknowledgments

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